

LIGHT SCANNING OPTICAL SYSTEM, OPTICAL SCANNING  
APPARATUS AND IMAGE FORMING APPARATUS USING THE SAME

BACKGROUND OF THE INVENTION

5 Field of the Invention

This invention relates to a light scanning optical  
system and an optical scanning apparatus using an  
oblique incidence optical system and an image forming  
apparatus using the same, and particularly to an  
10 apparatus such as a laser beam printer or a digital  
copier which well corrects the uniformity of the  
absolute value of the peak intensity in the light  
intensity distribution of a spot on a surface to be  
scanned and is thereby suitable for high-speed and  
15 highly definite image formation.

Related Background Art

A light scanning optical system (and an optical  
scanning apparatus) heretofore used in a laser beam  
printer or a digital copier or the like has a  
20 semiconductor laser as light source means, a first  
optical system for imaging a beam emitted from the  
light source means as a linear beam long in the main  
scanning direction near the deflecting surface of a  
light deflector, and a second optical system for  
25 imaging the beam reflected and deflected (deflected and  
scanned) by the light deflector on a surface to be  
scanned, and bringing the deflecting surface of the

light deflector and the surface to be scanned into a substantially conjugate relation in the sub-scanning cross-section.

5 The second optical system of such a light scanning optical system is an anamorphic imaging optical system called an  $f\theta$  lens, and has heretofore been constructed by the use of a plurality of expensive glass lenses and has been difficult to downsize.

10 In recent years, however, with the progress of the molding technique for plastics and the working technique for mold, it has become possible and has also been put into practical use to construct the imaging optical system ( $f\theta$  lens) comprised of a plurality of expensive glass lenses by the use of an inexpensive plastic lens.

15 However, it is still insufficient for the downsizing of the apparatus to simply replace the glass lenses with the plastic lens. Further, the same power as the power of the glass lenses is required of the plastic lens and therefore, the deterioration of imaging performance by the fluctuation of the environment when use is made of plastics inferior in environmental characteristic also poses a problem.

25 So, a light scanning optical system of a post-objective type having a converging lens disposed in the optical path between the light source and the light deflector before the beam is reflected and deflected by

the light deflector is known as realizing a compact and low-cost apparatus. Particularly, when the power of the  $f\theta$  lens is set to a small level in order to make the environmental characteristic good, the  $f\theta$  characteristic becomes under-corrected and therefore, it is often practised to make the deflecting surface of the light deflector into a convex shape. In this case, from the viewpoint of the symmetry of aberration correction, design is made such that the beam from the light source enters the light deflector at a predetermined angle from an oblique direction with respect to the deflecting surface of the light deflector, and it is often the case that the beam is reflected and deflected bisymmetrically with respect to the incident beam (with respect to the normal to the deflecting surface at the incidence point).

Also, in recent years, higher-speed and more highly definite performance has been required of apparatuses such as a laser beam printer and a digital copier.

To achieve the higher speed of the apparatus, it is necessary to rotate the light deflector at a high speed. Also, to achieve higher definition, it is necessary to make an imaged spot small in diameter and therefore, the width of the beam must be made great and accordingly, the light deflector itself for reflecting and deflecting the beam must also be made large.

To make the higher speed and higher definition compatible, the light deflector must be rotated at a high speed and be made large, but actually it is very difficult to satisfy the two at a time.

5           So, as a solution of such a problem, various light scanning optical systems using the so-called overfield scanning method designed such that the beam width in the main scanning direction of the beam incident on the deflecting surface of the light deflector enters  
10           (irradiates) astride the plurality of deflecting surfaces of the light deflector have been proposed and also put into practical use.

          In the overfield scanning method, there is the characteristic that the size of the imaged spot in the  
15           main scanning direction is varied by the scanning angle and therefore, in order to minimize the influence thereof, it is desirable to make such design that as in the prior art, the beam incident on the light deflector is not made to enter from the main scanning cross-  
20           section, but the beam emitted from the light source is incident on the light deflector at a predetermined angle from an oblique direction with respect to the deflecting surface of the light deflector, and the beam is reflected and deflected bisymmetrically with respect  
25           to the incident beam (with respect to the normal to the deflecting surface at the incident point).

          Further, the use of a multibeam laser source

having a plurality of light emitting portions as light source means in the above-described light scanning optical system becomes advantageous for further higher speed.

5           As another means for achieving a higher speed, there is known, for example, a light scanning optical system called a twice incidence scanning method of causing a beam emitted from a light source to be incident on a first deflecting surface of a light  
10   deflector, causing the beam reflected and deflected by this first deflecting surface to be again incident on a second deflecting surface differing from the first deflecting surface of the light deflector through a transmitting optical system, and effecting deflection  
15   and scanning.

          This twice incidence scanning method includes a method called a double angle scanning method, and a method called a surface following method in which a beam entering a second deflecting surface of a light  
20   deflector moves following the movement of the deflecting surface, but in both of the two methods, it is difficult to dispose a transmitting optical system in the deflecting surface and therefore, there is adopted a construction designed such that the beam  
25   emitted from the light source is incident on the light deflector at a predetermined angle from an oblique direction with respect to the deflecting surface of the

light deflector, and the transmitting optical system is disposed while being deviated in the sub-scanning direction with respect to the deflecting surface in the main scanning direction.

5           However, in the above-described prior-art light scanning optical system, optical scanning apparatus and image forming apparatus of such a construction that the beam emitted from the light source is caused to be incident on the light deflector at a predetermined  
10           angle from an oblique direction with respect to the deflecting surface of the light deflector, if as shown in Fig. 16 of the accompanying drawings, a beam (light beam) having a coordinate system of the main scanning direction y, the sub-scanning direction z and the  
15           optical axis direction x is incident on the deflecting surface 96a of a polygon mirror 96 at a predetermined angle with respect to the sub-scanning direction, the beam reflected and deflected there does not scan in a plane but scans on a conical plane and therefore, the  
20           coordinate system of the beam rotates. At this time, the coordinate system of the beam L0 at the center of scanning does not rotate, but yet beams L1 and L2 at the opposite ends of the scanning area have their coordinate systems rotated in opposite directions as  
25           shown in Fig. 17 of the accompanying drawings.

It is well known that there is the problem that even if the coordinate system at the opposite ends of

this scanning area tries to image the rotated beam on a surface to be scanned by an anamorphic imaging optical system, the beam spot shape (hereinafter simply referred to also as the "spot shape") is destroyed and is not converged at a point, and good imaging cannot be obtained on the surface to be scanned.

To this problem, in the conventional light scanning optical system of a construction in which the beam emitted from the light source is caused to be incident on the light deflector at a predetermined angle from an oblique direction with respect to the deflecting surface of the light deflector, a scanning lens or a correcting lens is disposed eccentrically in the sub-scanning direction or only a certain surface of a lens is made eccentric in the sub-scanning direction, whereby it is possible to improve the spot shape on the surface to be scanned to a certain degree.

Heretofore, when improving the spot shape, the spot shape has been improved by evaluating the degree of the expanse of a spot diagram, or the shape or the like of the equal altitude curve of the beam spot.

Actually, however, it is insufficient for obtaining a good image output to simply correct the spot shape well. Specifically, it is difficult to obtain a good image output unless the uniformity of the absolute value of the peak intensity in the light intensity distribution of the spot on the surface to be

scanned is corrected well. This is because even if the shape of the spot is corrected a little well, if the absolute value of the peak intensity is low, it becomes impossible to form a good electrostatic latent image on the surface of a photosensitive drum which is the surface to be scanned.

Heretofore, there has been the problem that the uniformity of the absolute value of the peak intensity in the light intensity distribution of the spot on the surface to be scanned is not taken into account and as the result, the output image is deteriorated.

For example, Japanese Patent Application Laid-Open No. 6-18800 discloses a light scanning optical system of a post-objective type designed such that a beam emitted from a light source is incident on a light deflector at a predetermined angle from an oblique direction with respect to the deflecting surface of the light deflector, and in which the shape of the deflecting surface in the main scanning cross-section is made into an elliptical shape and the entrance surface and exit surface of a correcting lens are made into a shape in which they are displaced in the sub-scanning direction and the spot shape is corrected to a certain degree. In this example, however, the destruction of the spot shape has its spot diagram only visually evaluated and further, the correction of the shape of the spot is still insufficient, and there has



been the problem that the uniformity of the absolute value of the peak intensity in the light intensity distribution of the spot on the surface to be scanned is not corrected and it is difficult to obtain a highly  
5 definite image output.

Japanese Patent Application Laid-Open No. 7-27991 discloses a light scanning optical system of the post-objective type designed such that a beam emitted from a light source is incident on a light deflector at a  
10 predetermined angle from an oblique direction with respect to the deflecting surface of the light deflector, and in which the shape of the deflecting surface in the main scanning cross-section is made into an elliptical shape and the entrance surface of a  
15 correcting lens is made into a shape in which it is displaced in the sub-scanning direction, and the spot shape is corrected to a certain degree. In this example, however, the curvature of image field in the main scanning direction by a light component widened in  
20 the sub-scanning direction of the beam (beam light) and the curvature of image field in the sub-scanning direction by a light component widened in the main scanning direction of the beam are only evaluated as the degree of the collapse of the spot shape, and this  
25 evaluating method can evaluate only the curvature of image field by a light component widened in a cross-section of a particular direction, and the curvature of

image field, etc. of light component widened in the other cross-sections are not taken into account.

Further, the correction of the curvature of image field in the main scanning direction is insufficient, and there has been the problem that the absolute value of the peak intensity in the light intensity distribution of the spot on the off-axis surface to be scanned is low relative to that on the axis and it is difficult to obtain a highly definite image output.

10 Japanese Patent Application Laid-Open No. 10-20230 discloses a light scanning optical system of the so-called surface following type in which a beam emitted from a light source is incident on a first deflecting surface of a light deflector, and the beam deflected by the first deflecting surface is again incident on a second deflecting surface of the light deflector differing from the first deflecting surface through a transmitting optical system, and the reincident light follows with the movement of the second deflecting surface, and in which a scanning lens is eccentrically disposed in the sub-scanning direction or the scanning lens is curved in the sub-scanning direction and the shape of a spot is corrected to a certain degree. In this example, however, the shape of the equal altitude curve of the beam spot is merely corrected well as the degree of the collapse of the shape of the spot. To obtain a good image output as previously described, it

is insufficient to simply correct the shape of the spot well, and the uniformity of the absolute value of the peak intensity in the light intensity distribution of the spot on the surface to be scanned must be corrected well, and this point is not at all taken into account, and this has led to the problem that it is difficult to obtain a good image output.

Japanese Patent Application Laid-Open No. 11-242179 discloses a post-objective type light scanning optical system designed such that a beam emitted from a light source is incident on a light deflector at a predetermined angle from an oblique direction with respect to the deflecting surface of the light deflector, and having a construction in which a scanning lens is shifted in the sub-scanning direction. In this example, however, only the curvature of scanning lines and  $f\theta$  characteristic and curvature of image field are evaluated, and the purpose of shifting the scanning lens in the sub-scanning direction takes only the curvature of scanning lines into account, and no consideration is taken about the collapse of the shape of the spot which greatly affects an output image, and this has led to the problem that it is difficult to obtain a good image output.

#### SUMMARY OF THE INVENTION

It is an object of the present invention to

provide a light scanning optical system and an optical scanning apparatus using an oblique incidence optical system and an image forming apparatus using the same in which the uniformity of the absolute value of the peak  
5 intensity in the light intensity distribution of a spot on a surface to be scanned is corrected well, whereby the deterioration of an output image attributable to the rotation of the spot which has heretofore posed a problem can be effectively corrected and high-speed and  
10 highly definite image formation can be effected.

According to one aspect of the invention, a light scanning optical system comprises an incidence optical system for causing a beam emitted from light source means to be incident on the deflecting surface of a  
15 light deflector at a predetermined angle in the sub-scanning cross-section, and an imaging optical system for imaging the beam reflected and deflected by the light deflector on a surface to be scanned, wherein when the maximum value and minimum value of the peak  
20 intensity in the effective scanning area of a spot imaged on the surface to be scanned by the imaging optical system are defined as  $E_{MAX}$  and  $E_{MIN}$ , respectively, the following condition is satisfied:

$$0.8 \leq \frac{E_{MIN}}{E_{MAX}}.$$

In the light scanning optical system according to another aspect of the invention, when the difference in

the incidence point in the sub-scanning direction on the surface to be scanned between the two marginal rays of the beam reflected and deflected by the deflecting surface of the light deflector in the main scanning direction is defined as  $\Delta s$  and the diameter of the spot imaged on the surface to be scanned which becomes  $1/e^2$  relative to the peak intensity in the sub-scanning direction is defined as  $D_s$ , the following condition is satisfied:

10 
$$\frac{\Delta s}{D_s} \leq 0.9.$$

In the light scanning optical system according to another aspect of the invention, when the beam width of the beam reflected and deflected by the deflecting surface of the light deflector in the main scanning direction is defined as  $d$  and the angle of incidence at which the beam from the incidence optical system is incident on the deflecting surface from an oblique direction with respect to a plane containing a normal to the deflecting surface of the light deflector in the sub-scanning cross-section and parallel to the main scanning direction is defined as  $\alpha$  and the scanning angle of the beam reflected and deflected by the deflecting surface of the light deflector is defined as  $\theta$  and the lateral magnification of the imaging optical system in the sub-scanning direction is defined as  $\beta$ , the following condition is satisfied:

$$\frac{2 \times d \times \tan\left(\frac{\theta}{2}\right) \times (\sin\alpha) \times \beta}{Ds} \leq 0.9.$$

In the light scanning optical system according to another aspect of the invention, the optical axis of at least one of lens surfaces constituting the imaging optical system in the sub-scanning cross-section is shifted in the sub-scanning direction relative to the center axis of the beam reflected and deflected by the deflecting surface and travelling toward the central position of the effective scanning area or/and is inclined in the sub-scanning direction.

In the light scanning optical system according to another aspect of the invention, the height of the optical axis of at least one of lens surface constituting the imaging optical system in the sub-scanning cross-section continuously varies in conformity with the lengthwise position in the main scanning direction.

In the light scanning optical system according to another aspect of the invention, at least some of lenses constituting the imaging optical system also constitute the incidence optical system.

In the light scanning optical system according to another aspect of the invention, the beam emitted from the light source means is incident on the deflecting surface of the light deflector in a state in which it

is wider than the width of the deflecting surface in the main scanning direction.

In the light scanning optical system according to another aspect of the invention, the beam emitted from  
5 the light source means is incident on the deflecting surface from substantially the center of the scanning angle by the light deflector.

In the light scanning optical system according to another aspect of the invention, at least one of lens  
10 surfaces constituting the imaging optical system has its radius of curvature in the sub-scanning cross-section continuously varied away from the optical axis of the lens in the main scanning direction.

In the light scanning optical system according to another aspect of the invention, the light source means  
15 is a multibeam laser source having a plurality of light emitting portions.

According to another aspect of the invention, there is provided an optical scanning apparatus  
20 characterized by using the above-described light scanning optical system.

According to another aspect of the invention, there is provided an image forming apparatus provided with the above-described optical scanning apparatus,  
25 and a printer controller for connecting code data inputted from an external device into an image signal and inputting it to the optical scanning apparatus.

In the above-described image forming apparatus according to another aspect of the invention, an image is formed by background exposure.

According to another aspect of the invention, a  
5 light scanning optical system comprises an incidence optical system for causing a beam emitted from light source means to be incident on the deflecting surface of a light deflector at a predetermined angle in the sub-scanning cross-section, and an imaging optical  
10 system for imaging the beam reflected and deflected by the light deflector on a surface to be scanned, and bringing the deflecting surface of the light deflector and the surface to be scanned into a substantially conjugate relation in the sub-scanning cross-section,  
15 characterized in that when the difference in the incidence point in the sub-scanning direction on the surface to be scanned between the two marginal rays of the beam reflected and deflected by the deflecting surface of the light deflector in the main scanning  
20 direction is defined as  $\Delta s$  and the diameter of a spot imaged on the surface to be scanned which becomes  $1/e^2$  relative to the peak intensity in the sub-scanning direction is defined as  $D_s$ , the following condition is satisfied:

25 
$$\frac{\Delta s}{D_s} \leq 0.9.$$

In the light scanning optical system according to



another aspect of the invention, when the beam width of the beam reflected and deflected by the deflecting surface of the light deflector in the main scanning direction is defined as  $d$  and the angle of incidence at which the beam from the incidence optical system is incident on the deflecting surface from an oblique direction with respect to a plane containing a normal to the deflecting surface of the light deflector in the sub-scanning cross-section and parallel to the main scanning direction is defined as  $\alpha$  and the scanning angle of the beam reflected and deflected by the deflecting surface of the light deflector is defined as  $\theta$  and the lateral magnification of the imaging optical system in the sub-scanning direction is defined as  $\beta$ , the following condition is satisfied:

$$\frac{2 \times d \times \tan\left(\frac{\theta}{2}\right) \times (\sin\alpha) \times \beta}{Ds} \leq 0.9.$$

In the light scanning optical system according to another aspect of the invention, the optical axis of at least one of lens surfaces constituting the imaging optical system in the sub-scanning cross-section is shifted in the sub-scanning direction with respect to the center axis of the beam reflected and deflected by the deflecting surface and travelling toward the central position of an effective scanning area or/and is inclined in the sub-scanning direction.

In the light scanning optical system according to another aspect of the invention, the height of the optical axis of at least one of lens surfaces constituting the imaging optical system in the sub-scanning cross-section continuously varies in conformity with the lengthwise position in the main scanning direction.

In the light scanning optical system according to another aspect of the invention, at least some of lenses constituting the imaging optical system also constitute the incidence optical system.

In the light scanning optical system according to another aspect of the invention, the beam emitted from the light source means is incident on the deflecting surface of the light deflector in a sate in which it is wider than the width of the deflecting surface in the main scanning direction.

In the light scanning optical system according to another aspect of the invention, the beam emitted from the light source means is incident on the deflecting surface from substantially the center of the scanning angle by the light deflector.

In the light scanning optical system according to another aspect of the invention, at least one of lens surfaces constituting the imaging optical system has its radius of curvature in the sub-scanning cross-section continuously varied away from the optical axis

of the lens in the main scanning direction.

In the light scanning optical system according to another aspect of the invention, the light source means is a multibeam laser source having a plurality of light  
5 emitting portions.

According to another aspect of the invention, there is provided an optical scanning apparatus characterized by using the above-described light scanning optical system.

10 According to another aspect of the invention, there is provided an image forming apparatus provided with the above-described optical scanning apparatus, and a printer controller for converting code data inputted from an external device into an image signal  
15 and inputting it to the optical scanning apparatus.

According to another aspect of the invention, there is provided the above-described image forming apparatus characterized in that an image is formed by background exposure.

20 According to another aspect of the invention, there is provided a light scanning optical system in which a beam emitted from light source means is caused by an incidence optical system to be incident on a first deflecting surface of a light deflector having a  
25 plurality of deflecting surfaces at a predetermined angle in the sub-scanning cross-section, and the beam reflected and deflected by the first deflecting surface

is caused to be again incident on a second deflecting surface of the light deflector differing from the first deflecting surface through a transmitting optical system, and the beam reflected and deflected by the second deflecting surface is imaged on a surface to be scanned by an imaging optical system, and in the sub-scanning cross-section, the deflecting surface of the light deflector and the surface to be scanned are brought into a substantially conjugate relation, characterized in that when the maximum value and minimum value of the peak intensity in the effective scanning area of a spot imaged on the surface to be scanned by the imaging optical system are defined as  $E_{MAX}$  and  $E_{MIN}$ , respectively, the following condition is satisfied:

$$0.8 \leq \frac{E_{MIN}}{E_{MAX}}.$$

In the light scanning optical system according to another aspect of the invention, when the difference in the incidence point in the sub-scanning direction on the surface to be scanned between the two marginal rays of the beam reflected and deflected by the second deflecting surface of the light deflector in the main scanning direction is defined as  $\Delta s$  and the diameter of the spot imaged on the surface to be scanned which becomes  $1/e^2$  relative to the peak intensity in the sub-scanning direction is defined as  $D_s$ , the following

condition is satisfied:

$$\frac{\Delta s}{Ds} \leq 0.9.$$

In the light scanning optical system according to another aspect of the invention, when the beam width of the beam reflected and deflected by the second deflecting surface of the light deflector in the main scanning direction is defined as  $d$  and the angle of incidence at which the beam from the incidence optical system is incident on the first deflecting surface from an oblique direction with respect to a plane containing a normal to the first deflecting surface of the light deflector in the sub-scanning cross-section and parallel to the main scanning direction is defined as  $\alpha$  and the scanning angle of the beam reflected and deflected by the second deflecting surface of the light deflector is defined as  $\theta$  and the lateral magnification of the imaging optical system in the sub-scanning direction is defined as  $\beta$ , the following condition is satisfied:

$$\frac{2 \times d \times \tan\left(\frac{\theta}{2}\right) \times (\sin\alpha) \times \beta}{Ds} \leq 0.9.$$

In the light scanning optical system according to another aspect of the invention, the optical axis of at least one of lens surfaces constituting the imaging optical system in the sub-scanning cross-section is

shifted in the sub-scanning direction relative to the center axis of the beam reflected and deflected by the deflecting surface and travelling toward the central position of the effective scanning area or/and is  
5 inclined in the sub-scanning direction.

In the light scanning optical system according to another aspect of the invention, the height of the optical axis of at least one of lens surfaces constituting the imaging optical system in the sub-  
10 scanning cross-section continuously varies in conformity with the lengthwise position in the main scanning direction.

In the light scanning optical system according to another aspect of the invention, at least some of  
15 lenses constituting the imaging optical system also constitute the incidence optical system.

In the light scanning optical system according to another aspect of the invention, the beam emitted from the light source means is incident on the first  
20 deflecting surface of the light deflector in a state in which it is wider than the width of the first deflecting surface in the main scanning direction.

In the light scanning optical system according to another aspect of the invention, the beam emitted from  
25 the light source means is incident on the first deflecting surface from substantially the center of the scanning angle by the light deflector.

In the light scanning optical system according to another aspect of the invention, at least one of lens surfaces constituting the imaging optical system has its radius of curvature in the sub-scanning cross-section continuously varied away from the optical axis of the lens in the main scanning direction.

In the light scanning optical system according to another aspect of the invention, the light source means is a multibeam laser source having a plurality of light emitting portions.

According to another aspect of the invention, there is provided an optical scanning apparatus using the above-described light scanning optical system.

According to another aspect of the invention, there is provided an image forming apparatus provided with the above-described optical scanning apparatus, and a printer controller for converting code data inputted from an external device into an image signal and inputting it to the optical scanning apparatus.

According to another aspect of the invention, there is provided the above-described image forming apparatus characterized in that an image is formed by background exposure.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross-sectional view of the essential portions of Embodiment 1 of the present invention in

the main scanning direction.

Fig. 2 is a cross-sectional view of the essential portions of Embodiment 1 of the present invention in the sub-scanning direction.

5        Fig. 3 shows the state of the incidence onto the light deflector of an underfield optical system.

Fig. 4 shows the state of the incidence onto the light deflector of an overfield optical system.

10       Fig. 5 shows the state of a beam incident on a correcting lens in Embodiment 1 of the present invention.

Fig. 6 shows the peak intensity ratio of an imaged spot in Embodiment 1 of the present invention.

15       Fig. 7 shows the imaging of a marginal ray in the main scanning direction in the sub-scanning oblique incidence.

Fig. 8 shows the relation between  $E_{\text{MIN}}/E_{\text{MAX}}$  and  $\Delta s/Ds$  on a surface to be scanned.

20       Fig. 9 shows the characteristic of  $\Delta s/Ds$  in Embodiment 1 of the present invention.

Figs. 10A and 10B illustrate the deviation in the sub-scanning direction of the marginal ray in the main scanning direction in oblique incidence.

25       Fig. 11 is a cross-sectional view of the essential portions of Embodiment 2 of the present invention in the main scanning direction.

Fig. 12 is a cross-sectional view of the essential



portions of Embodiment 2 of the present invention in the sub-scanning direction.

Fig. 13 shows the peak intensity ratio of an imaged spot in Embodiment 2 of the present invention.

5 Fig. 14 shows the characteristic of  $\Delta s/Ds$  in Embodiment 2 of the present invention.

Fig. 15 is a cross-sectional view of essential portions in the sub-scanning direction showing an example of the construction of an electrophotographic printer using the light scanning optical system of the present invention.

Fig. 16 illustrates the state after an obliquely incident beam is reflected and deflected by a light deflector.

15 Fig. 17 illustrates the coordinate system after the obliquely incident beam is reflected and deflected by the light deflector.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

20 Fig. 1 is a cross-sectional view (main scanning cross-sectional view) of essential portions of Embodiment 1 in the main scanning direction when the light scanning optical system (optical scanning apparatus) of the present invention is applied to an image forming apparatus such as a laser beam printer or  
25 a digital copier, and Fig. 2 is a cross-sectional view (sub-scanning cross-sectional view) of essential

portions in the sub-scanning direction of Fig. 1.

In these figures, the reference numeral 1 designates light source means comprising, for example, a semiconductor laser. The reference numeral 2 denotes a conversion element portion (collimator lens portion) having a first collimator lens (cemented lens) 2a and a second collimator lens 2b, and this conversion element portion 2 converts a divergent beam emitted from the light source means 1 into a weak divergent beam. The reference numeral 3 designates an aperture stop which limits the beam width of the passing beam in the sub-scanning direction and shapes the beam shape. The reference numeral 4 denotes a cylindrical lens having predetermined refractive power only in the sub-scanning direction, and this cylindrical lens 4 causes the beam passed through the aperture stop 3 to be imaged as a substantially linear image on a light deflecting surface to be described in the sub-scanning cross-section.

The collimator lens portion 2, the aperture stop 3 and the cylindrical lens 4 together constitute an element of a first optical system 51 which is an incidence optical system. In the present embodiment, the first optical system 51 is disposed so that the beam emitted from the light source means 1 may be incident on the deflecting surface 6a of a light deflector 6 at a predetermined angle from an oblique

direction in the sub-scanning cross-section (an oblique incidence optical system).

The reference numeral 6 designates a polygon mirror which is a light deflector rotated at a  
5 predetermined angular speed in the direction of arrow A by driving means (not shown) such as a motor.

The reference numeral 52 denotes an imaging optical system ( $f\theta$  lens system) as a second optical system having a scanning lens portion 11 and a  
10 correcting lens portion 12.

The scanning lens portion 11 has a first scanning lens 11a comprising a concave lens and a second scanning lens 11b comprising a convex lens, and causes  
15 the beam reflected and deflected at a predetermined angular speed by the light deflector 6 to be imaged on a surface 8 to be scanned chiefly in the main scanning direction, and also effects correction so that the beam may assume a constant speed on the surface 8 to be scanned. That is, the scanning lens portion 11 well  
20 corrects the curvature of image field and the  $f\theta$  characteristic chiefly in the main scanning direction. Also, it is of such a construction that before the beam having emerged from the first optical system 51 is incident on the deflecting surface 6a of the light  
25 deflector 6, the beam passes through the scanning lens portion 5 and then is incident on the deflecting surface 6a. That is, it is of such a construction that

the scanning lens portion 5 shares a part of the function of the first optical system 51. Such a construction will hereinafter be referred to as the double pass.

5           The correcting lens portion 12 has a single correcting lens 7 formed of a plastic material. The correcting lens 7 has little power in the main scanning direction and has strong power in the sub-scanning direction, and causes the beam reflected and deflected (deflected and scanned) by the light deflector 6 to be  
10           imaged on the surface 8 to be scanned chiefly in the sub-scanning direction, and also brings the deflecting surface 6a of the light deflector 6 and the surface 8 to be scanned into a substantially conjugate relation  
15           in the sub-scanning cross-section.

          The surface 8 to be scanned comprises, for example, the surface of a photosensitive drum.

          In the present embodiment, the divergent beam light-modulated and emitted from the semiconductor  
20           laser 1 is converted into a weak divergent beam by the collimator lens portion 2, and has its light amount limited by the aperture stop 3 and enters the cylindrical lens 4. Of the beam which has entered the cylindrical lens 4, the beam in the sub-scanning cross-  
25           section is converged and is transmitted through the second scanning lens 11b and the first scanning lens 11a and is incident on the deflecting surface 6a of the

light deflector 6, and is imaged as a substantially linear image (a linear image long in the main scanning direction) near the deflecting surface 6a. At this time, the beam incident on the deflecting surface 6a is  
5 incident on the deflecting surface 6a of the light deflector 6 at a predetermined angle from an oblique direction (an oblique incidence optical system). That is, the beam from the first optical system 51 is incident on the deflecting surface 6a from an oblique  
10 direction in the sub-scanning cross-section.

On the other hand, in the main scanning cross-section, the beam is transmitted through the second scanning lens 11b and the first scanning lens 11a in its intact state (the state of the weak divergent  
15 beam), whereby it is converted into a substantially parallel beam, and is incident on the deflecting surface 6a from substantially the center of the scanning angle by the light deflector 6 (front incidence). The beam width of the substantially  
20 parallel beam at this time is set so as to be sufficiently wide in the main scanning direction relative to the facet width of the deflecting surface 6a of the light deflector 6 (an overfield scanning optical system).

25 The beam reflected and deflected by the deflecting surface 6a of the light deflector 6 is then directed onto the surface 8 of the photosensitive drum through

the first scanning lens 11a, the second scanning lens 11b and the correcting lens 7, and optically scans the surface 8 of the photosensitive drum in the direction of arrow B (the main scanning direction) by the light deflector 6 being rotated in the direction of arrow A. Thereby, image recording is effected on the surface 8 of the photosensitive drum as a recording medium.

In the present embodiment, as shown in Fig. 3, the beam is caused to be incident in a state in which the beam width of the beam passed through the first optical system (not shown) in the main scanning direction is wider than the width of the deflecting surface 6a of the light deflector 6 in the main scanning direction (a so-called overfield optical system).

On the other hand, in a light scanning optical system heretofore generally used, as shown in Fig. 4, the beam is caused to be incident in a state in which the beam width of the beam passed through a first optical system (not shown) in the main scanning direction is narrower than the width of the deflecting surface 6a of the light deflector 6 in the main scanning direction (a so-called underfield optical system).

As can be seen from Figs. 3 and 4, when it is assumed that the beam width of the beam incident on the second optical system in the main scanning direction is the same, apparently the overfield optical system is

very advantageous for a higher speed and higher resolution because it is possible to set the light deflector 6 small and set the number of the deflecting surfaces to a great number.

5           On the other hand, if in the overfield optical system, as shown in Fig. 3, the beam to be caused to be incident on the light deflector 6 is caused to be incident from a direction similar to that in the underfield optical system, great asymmetry will occur  
10   to the beam width in the main scanning direction entering the second optical system at the opposite end portions of a scanning area in the main scanning direction. As the result, a great difference in the spot diameter in the main scanning direction will occur  
15   between the start side and end side of scanning on the surface to be scanned, and the light amount will also vary greatly.

Consequently, in the present embodiment, in order to restrain the above-noted evil to an allowable  
20   degree, as shown in Fig. 1, the beam to be caused to be incident on the light deflector 6 is caused to be incident from substantially the center of the scanning range in the main scanning direction (front incidence). That is, the beam emitted from the light source means 1  
25   is incident on the deflecting surface 6a from substantially the center of the scanning angle by the light deflector 6.

On the other hand, when such an incidence method is adopted, the first and second optical systems 51 and 52 cannot be disposed on the same plane (the main scanning plane) and therefore, the beam to be caused to be incident on the light deflector 6 is caused to be incident on the light deflector 6 from below at a predetermined angle with respect to the main scanning plane.

In the light scanning optical system using the so-called sub-scanning oblique incidence optical system (hereinafter simply referred to as the "oblique incidence optical system") like the present embodiment, as previously described, the plane the beam reflected and deflected by the deflecting surface 6a forms does not become a flat plane but forms a conical curved plane and thus, the beam is skew-incident on the correcting lens 7. Therefore, aberrations caused particularly at the end portions of the effective scanning area in the main scanning direction by the skew incidence adversely affect an imaged spot shape (hereinafter simply referred to as the "spot shape", and the spot shape is deteriorated and a desired spot shape becomes unobtainable. Further, under the influence of the skew incidence, the curvature of the scanning lines occurs on the surface 8 to be scanned at the same time.

The correcting lens 7 in the present embodiment



effectively corrects the deterioration of the spot shape by the skew incidence and at the same time, well corrects the curvature of the scanning lines by the correcting lens 7 being disposed so that the beam  
5 incident on the correcting lens 7 may be incident on a position deviating by a predetermined amount in the sub-scanning direction from the surface vertex in the sub-scanning cross-section at the central position of the correcting lens 7 in the main scanning direction,  
10 and the correcting lens 7 being tilted with respect to the beam incident on the correcting lens 7 at the center of the effective scanning area.

Specifically, as shown in Fig. 5, the beam incident on the correcting lens 7 is to be incident  
15 above the surface vertex in the sub-scanning cross-section of the correcting lens 7 in the sub-scanning direction, and the correcting lens 7 is tilted downwardly relative to the beam incident thereon.

Further, the correcting lens 7 in the present  
20 embodiment is of such a shape that the radius of curvature thereof in the sub-scanning cross-section continuously varies away from the optical axis of the lens in the main scanning direction. If the radius of curvature of the correcting lens 7 in the sub-scanning  
25 cross-section is kept constant, that is, the correcting lens 7 is made into a simple cylindrical shape and a toric shape, the curvature of image field in the sub-

scanning direction will remain. To restrain this curvature of image field in the sub-scanning direction to a small level, the correcting lens 7 can be brought close to the surface 8 to be scanned, but if it is brought too close, the correcting lens 7 will become long and this is not preferable. Also, it is possible to restrain the curvature of image field in the sub-scanning direction to a small level by keeping the radius of curvature of the correcting lens 7 in the sub-scanning cross-section constant, and making the correcting lens 7 into such a shape that the opposite end portions thereof are curved toward the surface 8 to be scanned. However, if the correcting lens 7 is made into the lens shape as described above, it will become difficult to correct the deterioration of the spot shape by the skew incidence.

Accordingly, the correcting lens 7 in the present embodiment is of such a shape that the radius of curvature thereof in the sub-scanning cross-section continuously varies in a direction away from the optical axis of the lens in the main scanning direction, so that the curvature of field in the sub-scanning direction is well corrected over the entire image range and deterioration of the spot shape due to the skew incidence is effectively corrected.

The correction of the deterioration of the spot shape in the oblique incidence optical system has

heretofore been variously done, and when improving the shape, the spot shape has been improved by effecting the evaluation of the degree of the expause of a spot diagram by geometrical-optical ray pursuit or the shape  
5 or the like of the equal intensity curve of a wave-optical imaged spot (hereinafter simply referred to also as the "spot").

Actually, however, it is often the case that even if the degree of the expause of the spot diagram by the  
10 geometrical-optical ray pursuit or the shape or the like of the equal intensity curve of the wave-optical imaged spot is corrected into a visually good shape, it is insufficient to obtain a good image output.

Specifically, it cannot be said to be sufficient  
15 unless the ratio between the absolute value of the peak intensity of the wave-optical intensity distribution of the spot at any scanning position on the surface 8 to be scanned and the absolute value of the peak intensity of the wave-optical intensity distribution of the spot  
20 in which the collapse of the center of scanning is relatively small is corrected so as to be equal to or greater than a certain value.

The deterioration of the spot shape in the oblique incidence optical system is caused chiefly by asymmetry  
25 being created in the aberration of the peripheral portion of the beam by the beam being skew-incident on the lens, but a certain degree of asymmetry is also

created in the aberration of the vicinity of the principal ray of the beam.

Such a deteriorated spot, if the asymmetry of the aberration in the peripheral portion of the beam is improved to a certain degree, will visually look like well corrected in the degree of the expanse of the spot diagram by the geometrical-optical ray pursuit of the spot or the shape of the equal intensity curve of the wave-optical spot.

However, it is often the case that the asymmetry of the aberration of the vicinity of the principal ray of the beam still remains and therefore the absolute value of the peak intensity of the wave-optical intensity distribution of the spot is not corrected to a sufficiently high level, as compared with the absolute value of the peak intensity of the central portion of scanning.

If the peak intensity is not corrected to a sufficiently high level, a good electrostatic latent image cannot be formed on the surface 8 to be scanned such as the photosensitive drum, and as the result, it becomes impossible to obtain a good output image.

According to the applicant's studies, it has been found that deterioration is recognized in the output image when the ratio  $E_{\text{MIN}}/E_{\text{MAX}}$  between the maximum value  $E_{\text{MAX}}$  and minimum value  $E_{\text{MIN}}$  of the absolute value of the peak intensity of the wave-optical intensity

distribution of each spot in the effective scanning area on the surface 8 to be scanned is below 0.8.

More specifically, when the ratio  $E_{\text{MIN}}/E_{\text{MAX}}$  lowers to the order of 0.8, there occurs the phenomenon that in the gradation pattern of halftone, in the case of low density, the reproducibility of each dot is deteriorated and density does not join and the image becomes blank in white, and in the case of high density, the spaces among dots are filled with black.

The result that deterioration is recognized in the output image when the ratio  $E_{\text{MIN}}/E_{\text{MAX}}$  is below 0.8 is generally called Strehl ratio intensity, and substantially coincides with the limit of the so-called Strehl ratio intensity in which the ratio  $I/I_0$  between the peak intensity  $I_0$  of a diffracted image in no-aberration and the peak intensity  $I$  of the diffracted image reduced in luminance by aberration is 0.8 or greater.

In a light scanning optical system used in an ordinary image forming apparatus or the like, the F number ( $F/\text{no.}$ ) on the surface to be scanned side in the main scanning and sub-scanning directions is of the order of 30 even if it is bright, and particularly at the scanning central position in the main scanning direction, asymmetrical aberrations hardly occur and therefore, it is not necessary to take the influence of high-order aberrations in the interior of the beam so

much into consideration. In this case, the maximum value  $E_{MAX}$  of the absolute value of the peak intensity of the wave-optical intensity distribution of the aforementioned spot may be considered to become

5 substantially equal to the peak intensity  $I_0$  of the diffracted image at no aberration.

However, in the light scanning optical system using the oblique incidence optical system like the present embodiment, as previously described, the beam

10 incident on the correcting lens 7 is caused to be incident above the surface vertex in the sub-scanning cross-section of the correcting lens 7 in the sub-scanning direction and therefore, asymmetrical aberration occurs in the sub-scanning direction even at

15 the scanning central position in the main scanning direction. In this case, the maximum value  $E_{MAX}$  of the absolute value of the peak intensity of the wave-optical intensity distribution of the spot does not become equal to the peak intensity  $I_0$  of the diffracted

20 image at no-aberration, but assumes a value somewhat lower than the peak intensity  $I_0$ .

The present embodiment is characterized in that the minimum value  $E_{MIN}$  of the absolute value of the peak intensity of the wave-optical intensity distribution of

25 each spot in the effective scanning area on the surface 8 to be scanned is not compared with the peak intensity  $I_0$  of the diffracted image at no-aberration, but is

compared with the maximum value  $E_{MAX}$  of the absolute value of the peak intensity of the wave-optical intensity distribution of each spot in the effective scanning area on the surface 8 to be scanned. That is, 5 the uniformity of the absolute value of the peak intensity in the light intensity distribution of the spot on the surface 8 to be examined is corrected well.

The reason why correction is effected as described above is that for example, the difference in gradation 10 by the difference in imaging performance depending on the location can be clearly visually confirmed and as an image, the quality is reduced and recognized, but when a generally minute aberration joins, as offset, even an image liable to be affected by imaging 15 performance like the gradation pattern or the like of halftone, the influence thereof is generally only a minute variation in the density of the image and the image is not recognized as being reduced in quality. what is important is the uniformity of the absolute 20 value of the peak intensity in the light intensity distribution of the spot on the surface 8 to be scanned.

In the present embodiment, with the ratio of the absolute value of the above-mentioned peak intensity as 25 a measure for evaluation, as shown in Fig. 6, the deterioration of the spot shape is corrected so that the ratio between the maximum value  $E_{MAX}$  and minimum

value  $E_{MIN}$  of the absolute value of the peak intensity of the wave-optical intensity distribution of each spot in the effective scanning area on the surface 8 to be scanned may satisfy the condition that

$$0.8 \leq \frac{E_{MIN}}{E_{MAX}}, \dots\dots (1)$$

whereby, there is obtained a light scanning optical system in which the deterioration of the output image is corrected effectively and which is suitable for a highly definite image output.

Specifically, to correct the deterioration of the spot shape so that the ratio  $E_{MIN}/E_{MAX}$  between the maximum value  $E_{MAX}$  and minimum value  $E_{MIN}$  of the absolute value of the peak intensity of the wave-optical intensity distribution of each spot in the effective scanning area on the surface 8 to be scanned may be 0.8 or greater, it can be substantially achieved by correcting the difference  $\Delta s$  in the incidence point (arrival point) in the sub-scanning direction on the surface 8 to be scanned between the two marginal rays of the beam reflected and deflected by the deflecting surface 6a in the main scanning direction to a certain value or less.

Here, description will be made in detail with reference to Fig. 7. Fig. 7 is a schematic view of essential portions showing the manner in which the beam at the end portion of the effective scanning area in the present embodiment passes through the second



optical system 52 and is incident on the surface 8 to be scanned.

In Fig. 7, the two marginal rays U and L of the beam in the main scanning direction, because the coordinate system of the beam rotates as previously described, cannot concentrate at a point, but is incident on a position spaced apart by  $\Delta s$  chiefly in the sub-scanning direction as shown in Fig. 7 when they are incident on the surface 8 to be scanned by the second optical system 52.

On the other hand, the two marginal rays U and L of the beam at the central portion of scanning in the main scanning direction, because the coordinate system of the beam is not rotating, do not deviate in the sub-scanning direction when they are incident on the surface 8 to be scanned. Fig. 8 shows the result of the simulation of the relation between the aforementioned  $E_{\text{MIN}}/E_{\text{MAX}}$  and  $\Delta s/D_s$  when such diameter (spot diameter) of the spot when as described above, the two marginal rays U and L in the main scanning direction do not deviate from each other that becomes  $1/e^2$  (e: the bottom of a natural logarithm) relative to the peak intensity in the sub-scanning direction is defined as  $D_s$  and there is no defocus in the image planes in the main scanning and sub-scanning directions. It can be apparently seen from Fig. 8 that in order that the ratio  $E_{\text{MIN}}/E_{\text{MAX}}$  between the maximum

value  $E_{MAX}$  and minimum value  $E_{MIN}$  of the absolute value of the peak intensity of the wave-optical intensity distribution of each spot in the effective scanning area on the surface 8 to be scanned may be 0.8 or greater, the ratio  $\Delta s/Ds$  must be 0.9 or less.

So, in the present embodiment, in order that the ratio  $E_{MIN}/E_{MAX}$  may be 0.8 or greater, specifically  $\Delta s/Ds$  which is the ratio between the amount of deviation  $\Delta s$  in the sub-scanning direction when the two marginal rays U and L of the beam in the main scanning direction are incident on the surface 8 to be scanned and such diameter  $Ds$  of the spot when the two marginal rays U and L in the main scanning direction do not deviate from each other that becomes  $1/e^2$  relative to the peak intensity in the sub-scanning direction is corrected so as to satisfy the condition that

$$\frac{\Delta s}{Ds} \leq 0.9, \dots (2)$$

as shown in Fig. 9.

The above-mentioned conditional expression (2) is the condition when as previously described, there is no defocus in the image planes in the main scanning and sub-scanning directions, and when there is any defocus in the image planes in the main scanning and sub-scanning directions, the upper limit value of the above-mentioned conditional expression (2) must be a smaller value. Consequently, in a light scanning

optical system using an ordinary oblique incidence optical system, to satisfy the above-mentioned conditional expression (1) in order to effectively correct the deterioration of the output image and obtain a highly definite image output, the above-mentioned conditional expression (2) must be satisfied without fail.

In the present embodiment, there is obtained a light scanning optical system in which the deterioration of the spot shape is corrected so as to satisfy both of the above-mentioned conditional expressions (1) and (2) to thereby correct the deterioration of the output image effectively and which is suitable for a highly definite image output.

Table 1 below shows the characteristics of the light scanning optical system according to the present embodiment.

In Table 1,  $R_m$  and  $R_s$  represent the radii of curvature in the main scanning cross-section and the sub-scanning cross-section, respectively. The shape of the correcting lens 7 in the main scanning cross-section is an arcuate shape of which the radius of curvature is  $R$ , while on the other hand, the shape thereof in the sub-scanning cross-section is such that the radius of curvature  $\gamma'$  is which the lens surface coordinate in the main scanning direction is  $Y$  is represented by the following expression:

$$\gamma' = \gamma (1 + D_2 Y^2 + D_4 Y^4 + D_6 Y^6 + D_8 Y^8 + D_{10} Y^{10})$$

( $\gamma$  is the radius of curvature on the optical axis,  
and  $D_2, D_4, D_6, D_8$  and  $D_{10}$  are coefficients.)

Table 1

wavelength used	$\lambda$ (nm)	655	
lightsource - first surface of collimator lens	d0	32.55	
collimator lens	radius of curvature	thickness	refractive index
first surface of collimator lens	117.9	2.00	1.74742
second surface of collimator lens	17.4	3.00	1.63678
third surface of collimator lens	-22.3	11.68	1
fourth surface of collimator lens	-56.2	5.00	1.51389
fifth surface of collimator lens	$\infty$	-	1
distance between fifth surface of collimator lens and aperture stop	d5	7.53	
shape of aperture stop	main scanning $7.5 \times$ sub-scanning 2.6 lectangular shape		
aperture stop - first surface of cylindrical lens	d6	10.50	
cylindrical lens	radius of curvature	thickness	refractive index
first surface of cylindrical lens	Rm: $\infty$ Rs:48.1	6	1.51389
second surface of cylindrical lens	$\infty$	-	1
second surface of cylindrical lens - polygon reflecting point	d7	333.13	
polygon reflecting point - first surface of scanning lens	d8	24.81	
scanning lens	radius of curvature	thickness	refractive index
first surface of scanning lens	Rm:-356 Rs: $\infty$	4.00	1.77610
second surface of scanning lens	$\infty$	41.50	1
third surface of scanning lens	$\infty$	15.00	1.69658
fourth surface of scanning lens	-152.6	-	1
fourth surface of scanning lens - first surface of correcting lens	d12	299.40	
shape of correcting lens			
first surface		second surface	
Rm	-1200.000	Rm	-1200.000
Rs	114.000	Rs	-120.000
D2	6.700E-06	D2u	7.900E-06
D4	0.000E+00	D4u	0.000E+00
D6	0.000E+00	D6u	0.000E+00
D8	0.000E+00	D8u	0.000E+00
D10	0.000E+00	D10u	0.000E+00
thickness of correcting lens	d13	4.00	
refractive index of correcting lens	N13	1.52757	
correcting lens - surface to be scanned	d14	166.28	
sub-scanning magnification of second optical system (scanning lens and correcting lens)	$\beta$	0.570	

amount of shift of first surface and second surface of correcting lens in the sub-scanning direction	Shift	-1.57
amount of tilt of first surface and second surface of correcting lens	Tilt	-0.80
sub-scanning angle of incidence on first optical system	$\alpha$	0.80
maximum scanning angle	$\theta_{\max}$	27.00
polygon	$\phi 29$	
	dodecahedron	

Reference is now had to Figs. 10A and 10B to describe the phenomenon that when the beam at the end portion of the effective scanning area passes through the scanning lens portion 5 and the correcting lens portion 7 and is incident on the surface 8 to be scanned, the two marginal rays U and L in the main scanning direction are incident on positions spaced apart by  $\Delta s$  in the sub-scanning direction.

Fig. 10A is a main scanning cross-sectional view showing the optical path along which the beam passed through the first optical system (not shown) in the present embodiment is reflected and deflected by the deflecting surface 6a of the light deflector 6 and passes to the surface 8 to be scanned via the second optical system 52, and Fig. 10B is a sub-scanning cross-sectional view of Fig. 10A. In order to simplify the description, the second optical system 52 is depicted typically.

Assuming that when the maximum scanning angle of the beam reflected and deflected by the deflecting surface 6a of the light deflector 6 is  $\theta$ , the beam width of the beam reflected and deflected by the deflecting surface in the main scanning direction is  $d$ , the positions at which the two marginal rays U and L in the main scanning direction are reflected and deflected by the deflecting surface 6a of the light deflector 6 deviate by  $P$  from each other in X direction in the

shown coordinate system. This amount of deviation P is represented as

$$P = d \times \tan \frac{\theta}{2}$$

by the use of the scanning angle  $\theta$  and the beam width d.

When as previously described, the two marginal rays U and L in the main scanning direction deviate by P from each other in X direction in the shown coordinate system, a deviation of  $\Delta d$  occurs between these two marginal rays U and L in a cross-section perpendicular to the direction in which the beam after reflected and deflected by the deflecting surface 6a of the light deflector 6 travels.

This amount of deviation  $\Delta d$  is represented as

$$\Delta d = 2 \times d \times \tan \left( \frac{\theta}{2} \right) \times \sin \alpha$$

by the use of the angle (hereinafter referred to also as the "angle of oblique incidence)  $\alpha$  at which the beam from the first optical system is incident on the deflecting surface 6a of the light deflector 6 from an oblique direction in the sub-scanning cross-section.

Assuming here that the lateral magnification of the second optical system in the sub-scanning direction is  $\beta$ , the two marginal rays U and L have their incidence points (arrival points) deviated from each other by an amount corresponding to the above-mentioned



amount of deviation  $\Delta d$  multiplied by the lateral magnification  $\beta$  in the sub-scanning direction on the surface 8 to be scanned.

5 The amount of deviation  $\Delta s$  at this time is represented as

$$\Delta s = 2 \times d \times \tan\left(\frac{\theta}{2}\right) \times (\sin\alpha) \times \beta.$$

Consequently, the above-mentioned conditional expression (2) can be represented as follows:

$$\frac{2 \times d \times \tan\left(\frac{\theta}{2}\right) \times (\sin\alpha) \times \beta}{Ds} \leq 0.9 \dots\dots (3)$$

That is, by suitably setting the scanning angle  $\theta$ , the beam width  $d$ , the angle of oblique incidence  $\alpha$ , the lateral magnification  $\beta$ , etc. so as to satisfy the above-mentioned conditional expression (3) within the entire effective scanning range, it becomes possible to obtain a light scanning optical system in which the deterioration of the output image is corrected effectively and which is suitable for a highly definite image output.

The above-mentioned conditional expression (3) supposes a case where the optical axis of the second optical system 52 in the sub-scanning cross-section coincides with the center axis of the beam deflected and scanned by the deflecting surface 6a of the light deflector 6 and travelling toward the central position

of the effective scanning area. That is, when the second optical system 52 is honestly disposed, it becomes requisite to satisfy the above-mentioned conditional expression (3).

5           On the other hand, when as in the present embodiment, the correcting lens 7 is disposed while being deviated by a predetermined amount in the sub-scanning direction relative to the center axis of the  
10           aforementioned beam, or is disposed while being tilted by a predetermined amount in the sub-scanning direction, it is possible to correct the value of the amount of deviation  $\Delta s$  by that disposition so as become smaller and therefore, it does not always become  
15           requisite to satisfy the above-mentioned conditional expression (3). However, if the angle of oblique incidence  $\alpha$ , the lateral magnification  $\beta$ , the scanning angle  $\theta$  etc. are set beyond the range of the above-mentioned conditional expression (3), the setting for satisfying the aforementioned conditional expression  
20           (1)

$$0.8 \leq \frac{E_{MIN}}{E_{MAX}}.$$

will become difficult and therefore, it is desirable to satisfy the above-mentioned conditional expression (3).

In the present embodiment, use is made of a light deflector (polygon mirror comprising a dodecahedron having a circumcircle diameter of 29 mm, and the

maximum scanning angle  $\theta$  is  $27^\circ$  and therefore, the width  $d$  of the beam reflected and deflected by this light deflector is

$$d = 7.56 \text{ (mm)}.$$

- 5 Also, the angle of oblique incidence  $\alpha$  is  $0.8^\circ$ , the lateral magnification  $\beta$  is 0.57 time and the spot diameter  $D_s$  of Embodiment 1 in the sub-scanning direction is 0.064 mm (64  $\mu\text{m}$ ) and therefore,

$$\frac{2 \times d \times \tan\left(\frac{\theta}{2}\right) \times (\sin \alpha) \times \beta}{D_s} = \frac{2 \times 7.56 \times \tan\left(\frac{27}{2}\right) \times \sin 0.8 \times 0.57}{0.064} \leq 0.9,$$

..... (3)

and this satisfies the above-mentioned conditional expression (3).

In the present embodiment, as described above, there is obtained a light scanning optical system in which the deterioration of the spot shape is corrected so as to satisfy the above-mentioned conditional expression 1 prescribing the ratio between the maximum value  $E_{\text{MAX}}$  and minimum value  $E_{\text{MIN}}$  of the absolute value of the peak intensity of the wave-optical intensity distribution of each spot in the effective scanning area on the surface 8 to be scanned, whereby the deterioration of the output image is corrected effectively, and which is suitable for a highly definite image output.

More specifically, there is obtained a light scanning optical system in which the beam incident on the correcting lens 7 is caused to be incident while being displaced by a predetermined amount in the sub-scanning direction from the surface vertex in the sub-scanning cross-section and further, the correcting lens 7 is tilted to thereby correct the deterioration of the spot shape and the curvature of the scanning lines, and the angle of oblique incidence  $\alpha$ , the lateral magnification  $\beta$  of the second optical system in the sub-scanning direction, the maximum scanning angle  $\theta$ , etc. are appropriately set to thereby satisfy the above-mentioned conditional expressions (2) and (3), whereby the deterioration of the output image is corrected effectively, and which is suitable for a highly definite image output.

While in the present embodiment, the correcting lens 7 is tilted to thereby correct chiefly the curvature of the scanning lines, it is also possible to continuously vary the height of the optical axis of at least one surface of the correcting lens in the sub-scanning cross-section in conformity with the lengthwise position in the main scanning direction to thereby correct the curvature of the scanning lines.

Also, while in the present embodiment, the correcting lens 7 is displaced, this is not restrictive, but other lens constituting the second

optical system 52 may be displaced.

Also, while in the present embodiment, the scanning optical system is comprised of a so-called overfield scanning system advantageous for a higher speed and higher definition, it is also possible to use a multibeam laser source or the like having a plurality of light emitting portions as the light source means to thereby make a construction more advantageous for a higher speed and higher definition.

10 [Embodiment 2]

Fig. 11 is a cross-sectional view of the essential portions, in the main scanning direction, of Embodiment 2 when the light scanning optical system (optical scanning apparatus) of the present invention is applied to an image forming apparatus such as a laser beam printer or a digital copier, and Fig. 12 is a cross-sectional view of the essential portions in the sub-scanning direction of Fig. 11. In Fig. 12, for the sake of simplicity, the essential portions are shown with a first optical system omitted. In Figs. 11 and 12, the same elements as the elements shown in Figs. 1 and 2 are given the same reference numerals.

The differences of the present embodiment from the aforescribed Embodiment 1 are that the light scanning optical system is comprised of an underfield scanning optical system, and that a second optical system 62 is comprised of two first and second scanning lenses 62a

and 62b. In the other points, the construction and optical action of Embodiment 2 are substantially similar to those of Embodiment 1, whereby a similar effect is obtained.

5           That is, in Figs. 11 and 12, the reference numeral designates a second optical system having a first scanning lens 62a formed of a plastic material and having its concave surface facing the light deflector 6 side and having strong positive power, and a second  
10       scanning lens 62b formed of a plastic material and having its convex surface facing the light deflector 6 side and having weak positive power, and the optical axes of the first and second scanning lenses 62a and 62b are both disposed in the main scanning cross-  
15       section.

          In the present embodiment, the first optical system 61 is comprised of a so-called underfield scanning optical system which causes a beam passed therethrough to be incident in a state in which the  
20       beam width thereof in the main scanning direction is narrower than the width of the deflecting surface 6a of the light deflector 6, and the beam caused to be incident on the deflecting surface 6a of the light deflector 6 is caused to be incident at an angle of  
25       1.3° with respect to the main scanning plane in the sub-scanning cross-section.

          That is, in the present embodiment, the first and

second scanning lenses 62a and 62b are disposed such that the beam from the deflecting surface 6a incident thereon is incident on a position deviating by a predetermined amount upwardly in the sub-scanning direction from the surface vertex in the sub-scanning cross-section at the central position of the first and second scanning lenses 62a and 62b in the main scanning direction, and are disposed such that the first and second scanning lenses 62a and 62b are downwardly tilted with respect to the incident beam.

While in the aforescribed Embodiment 1, only the correcting lens is disposed as described above, in the present embodiment, the two first and second scanning lenses 62a and 62b are disposed as described above, whereby the correction of the spot shape and the correction of the curvature of the scanning lines are effected more effectively.

Fig. 13 is an illustration showing the ratio between the maximum value  $E_{MAX}$  and minimum value  $E_{MIN}$  of the absolute value of the peak intensity of the wave-optical intensity distribution of each spot in the effective scanning area on the surface to be scanned in the present embodiment. As shown in Fig. 13, the aforementioned conditional expression (1) is satisfied over the entire effective scanning area, whereby there is obtained a light scanning optical system which is free of the deterioration of the output image and is

suitable for a highly definite image output.

Fig. 14 is an illustration showing the characteristic value of  $\Delta s/Ds$  in the present embodiment. As shown in Fig. 14, the aforementioned conditional expressions (2) and (3) are satisfied over the entire effective scanning area, whereby there is obtained a light scanning optical system which is free of the deterioration of the output image and is suitable for a highly definite image output.

Table 2 below shows the characteristics of the light scanning optical system according to the present embodiment.

In Table 2, the aspherical shape of the first and second scanning lenses in the main scanning cross-section, when the point of intersection between each lens surface and the optical axis is the origin and the direction of the optical axis is defined as the X-axis and the axis orthogonal to the optical axis in the main scanning cross-section is defined as the Y-axis and the axis orthogonal to the optical axis in the sub-scanning cross-section is defined as the Z-axis, is represented by the following expression:

$$X = \frac{y^2/Rm}{1 + (1 - (1+k)(y/Rm)^2)^{1/2}} + B_4 y^4 + B_6 y^6 + B_8 y^8 + B_{10} y^{10},$$

where  $Rm$  is the radius of curvature, and  $k$  and  $B_4$ - $B_{10}$  are aspherical surface coefficients.

Also, as regards the shape of the sub-scanning



cross-section, the radius of curvature  $R_s'$  of which the lens surface coordinates in the main scanning direction are  $Y$  is represented by the following expression:

$$R_s' = R_s(1 + D_2 Y^2 + D_4 Y^4 + D_6 Y^6 + D_8 Y^8 + D_{10} Y^{10}),$$

5 where  $R_s$  is the radius of curvature on the optical axis, and  $D_1 - D_{10}$  are coefficients.

Table 2

wavelength used		$\lambda(\text{nm})$	780
incident light on polygon		parallel beam	
shape of aperture stop		main scanning $3.08 \times$ sub-scanning 3.64 elliptical shape	
aperture stop - cylindrical lens		d1	10.00
cylindrical lens - polygon reflecting point		d2	111.80
polygon reflecting point - first surface of scanning lens		d3	24.50
shape of first scanning lens			
first surface		second surface	
Rm	-62.044	Rm	-35.199
k	-4.611E+00	k	-2.130E+00
B4	2.852E-06	B4	-4.482E-07
B6	0.000E+00	B6	2.061E-09
B8	0.000E+00	B8	-2.364E-14
B10	0.000E+00	B10	0.000E+00
Rs	-62.044	Rs	-59.177
D2	1.052E-03	D2u	-6.238E-05
D4	3.610E-06	D4u	-1.980E-06
D6	-4.197E-09	D6u	2.961E-09
D8	-7.328E-12	D8u	0.000E+00
D10	2.274E-14	D10u	0.000E+00
thickness of first scanning lens		d4	8.00
refractive index of first scanning lens		N1	1.5242
first scanning lens - second scanning lens		d5	15.37
shape of second scanning lens			
first surface		second surface	
Rm	87.010	Rm	85.490
k	-8.976E-01	k	-1.633E+01
B4	-4.413E-06	B4	-3.137E-06
B6	2.330E-09	B6	1.421E-09
B8	-7.821E-13	B8	-3.962E-13
B10	8.994E-17	B10	2.396E-17
Rs	-37.273	Rs	-13.718
D2	3.609E-03	D2u	1.253E-03
D4	3.975E-06	D4u	-1.133E-06
D6	6.179E-11	D6u	7.296E-10
D8	-5.225E-13	D8u	-2.746E-13
D10	0.000E+00	D10u	4.203E-17

thickness of second scanning lens	d6	7.00
refractive index of second scanning lens	N2	1.5242
second scanning lens - surface to be scanned	d7	119.00
sub-scanning magnification of second optical system (scanning lens)	$\beta$	2.240
amount of shift of first surface and second surface of first scanning lens in sub-scanning direction	Shift1	-0.55
amount of tilt of first surface and second surface of first scanning lens	Tilt1	-1.30
amount of shift of first surface and second surface of second scanning lens in sub-scanning direction	Shift2	-1.02
amount of tilt of first surface and second surface of second scanning lens	Tilt2	-1.30
sub-scanning angle of incidence on first optical system	$\alpha$	1.30
maximum scanning angle	$\theta_{\max}$	45.00
polygon	$\phi 40$ hexahedron	

While in each of Embodiments 1 and 2, the defecting surface of the light deflector is supposed as a flat surface, it is also possible that the beam incident on this light deflector is a convergent beam and the shape of the deflecting surface is a convex surface shape or the light scanning optical system is a light scanning optical system of the post-objective type. In the case of the light scanning optical system of this post-objective type, an oblique incidence optical system is requisite from the symmetry of aberration correction and therefore, the light scanning optical system of the present invention can be said to be best suited. Also, in the case of the light scanning optical system of the post-objective type, the power of the scanning lens constituting the second optical system (the  $f\theta$  lens system) in the main scanning direction can be weakened and therefore, it becomes possible to reduce the deterioration of the optical characteristic to the environmental fluctuation when an inexpensive plastic material is used for the scanning lens and thus, by applying the light scanning optical system of the present invention, it is possible to obtain a light scanning optical system more suitable for a high quality of image.

Also, while in each of Embodiments 1 and 2, there has been shown a light scanning optical system in which the beam from the first optical system is reflected and

deflected only once by the deflecting surface of the light deflector to thereby effect light scanning, the present invention is not restricted thereto, but like the aforescribed Embodiments 1 and 2, the present invention can also be applied to a so-called twice-incidence scanning type light scanning optical system of a construction in which, for example, a beam from a first optical system is caused to be incident on a first deflecting surface of a light deflector and the beam reflected and deflected by this first deflecting surface is caused to be again incident on a second deflecting surface of the light deflector through a transmitting optical system.

That is, in this twice-incidence scanning type light scanning optical system, for example, a beam emitted from light source means is caused by the first optical system to be incident on the first deflecting surface of the light deflector at a predetermined angle from an oblique direction in the sub-scanning cross-section, and the beam reflected and deflected by the first deflecting surface is transmitted through a first lens and is reflected by a first mirror, and the beam reflected by the first mirror is transmitted through second and third lenses and is reflected by a second mirror, whereafter it is caused to be incident again on a second deflecting surface of the light deflector differing from the first deflecting surface, and is

reflected and deflected by the second deflecting surface, whereafter a spot is formed on the surface to be scanned by a second optical system to thereby effect light scanning. The first, second and third lenses and  
5 the first and second mirrors together constitute an element of the transmitting optical system.

Such a twice-incidence scanning type light scanning optical system always assumes the construction of an oblique incidence optical system, and the  
10 uniformity of the peak intensity by the collapse of the spot shape as previously described poses a problem. By applying the light scanning optical system according to Embodiment 1 or 2 of the present invention to the twice-incidence scanning type, the uniformity of the  
15 peak intensity of the spot which has heretofore posed a problem is improved, and it becomes possible to obtain a light scanning optical system more advantageous for a high-speed and highly definite image output.

Fig. 15 is a cross-sectional view of essential  
20 portions in the sub-scanning direction showing an example of the construction of an electrophotographic printer which is an image forming apparatus using the light scanning optical system (optical scanning apparatus) of the present invention.

25 In Fig. 15, the reference numeral 104 designates the image forming apparatus. Code data Dc is inputted from an external device 117 such as a personal computer

to this image forming apparatus 104. This code data Dc is converted into image data (dot data) Di by a printer controller 111 in the apparatus. This image data Di is inputted to an optical scanning unit 100 having the construction shown in Embodiments 1 to 2. A light beam 103 modulated in conformity with the image data Di is emitted from this optical scanning unit 100, and by this light beam 103, the photosensitive surface of a photosensitive drum 101 is scanned in the main scanning direction.

The photosensitive drum 101 which is an electrostatic latent image bearing member (photosensitive body) is clockwisely rotated by a motor 115. With this rotation, the photosensitive surface of the photosensitive drum 101 moves relative to the light beam 103 in the sub-scanning direction orthogonal to the main scanning direction. Above the photosensitive drum 101, a charging roller 102 for uniformly charging the surface of the photosensitive drum 101 is provided so as to abut against the surface of the drum 101. The light beam 103 scanned by the optical scanning unit 100 is applied to the surface of the photosensitive drum 101 charged by the charging roller 102.

As previously described, the light beam 103 is modulated on the basis of the image data Di, and by this light beam 103 being applied, an electrostatic latent image is formed on the surface of the

photosensitive drum 101. This electrostatic latent image is developed as a toner image by a developing device 107 disposed so as to abut against the photosensitive drum 101 further downstream of the applied position of the light beam 103 with respect to the direction of rotation of the photosensitive drum 101.

The toner image developed by the developing device 107 is transferred onto paper 112 which is a transferring material by a transferring roller 108 disposed below the photosensitive drum 101 so as to be opposed to the photosensitive drum 101. The paper 112 is contained in a paper cassette 109 disposed forwardly (on the right side as viewed in Fig. 15) of the photosensitive drum 101 but paper feeding can also be manually done. A paper feeding roller 110 is disposed at an end portion of the paper cassette 109 and feeds the paper 112 in the paper cassette 109 into a conveying path.

The paper 112 to which the unfixed toner image has been transferred in the manner described above is further conveyed to a fixing device disposed rearwardly (on the left side as viewed in Fig. 15) of the photosensitive drum 101. The fixing device is comprised of a fixing roller 113 having a fixing heater (not shown) therein and a pressurizing roller 114 disposed so as to be in pressure contact with the



fixing roller 113, and pressurizes and heats the paper 112 conveyed from the transferring portion in the pressure contact portion between the fixing roller 113 and the pressurizing roller 114 to thereby fix the unfixed toner image on the paper 112. Further, paper discharge rollers 116 are disposed rearwardly of the fixing roller 113 and discharge the fixed paper 112 out of the image forming apparatus.

Although not shown in Fig. 15, the printer controller 111 effects not only the aforescribed conversion of the data, but also the control of various portions in the image forming apparatus including the motor 115 and a polygon motor, etc. in the optical scanning unit which will be described later.

The above-described image forming apparatus is also suitable for an image forming apparatus of the so-called background exposure type in which, for example, a portion not exposed by a spot imaged on a surface to be scanned is developed as an image. In the case of the image forming apparatus of the background exposure type, it is necessary to expose, for example, a back white portion free of image information by a spot. If in this case, the deterioration of the spot by an oblique incidence optical system is not sufficiently corrected, there will occur the phenomenon that the back white does not perfectly become white and the deteriorated portion of the spot is fogged blackly.

In the image forming apparatus of the present invention, the uniformity of the absolute value of the peak intensity in the light intensity distribution of the spot is corrected well and therefore, even if the background exposure type is adopted, it becomes possible to obtain output images of a high quality free of fog.

According to the present invention, as previously described, there can be achieved a light scanning optical system and an optical scanning apparatus using an oblique incidence optical system, and an image forming apparatus using the same in which the uniformity of the peak intensity in the light intensity distribution of the spot on the surface to be scanned which has heretofore not been considered is corrected well, whereby which are high in speed and definition and generally compact and simple in construction.